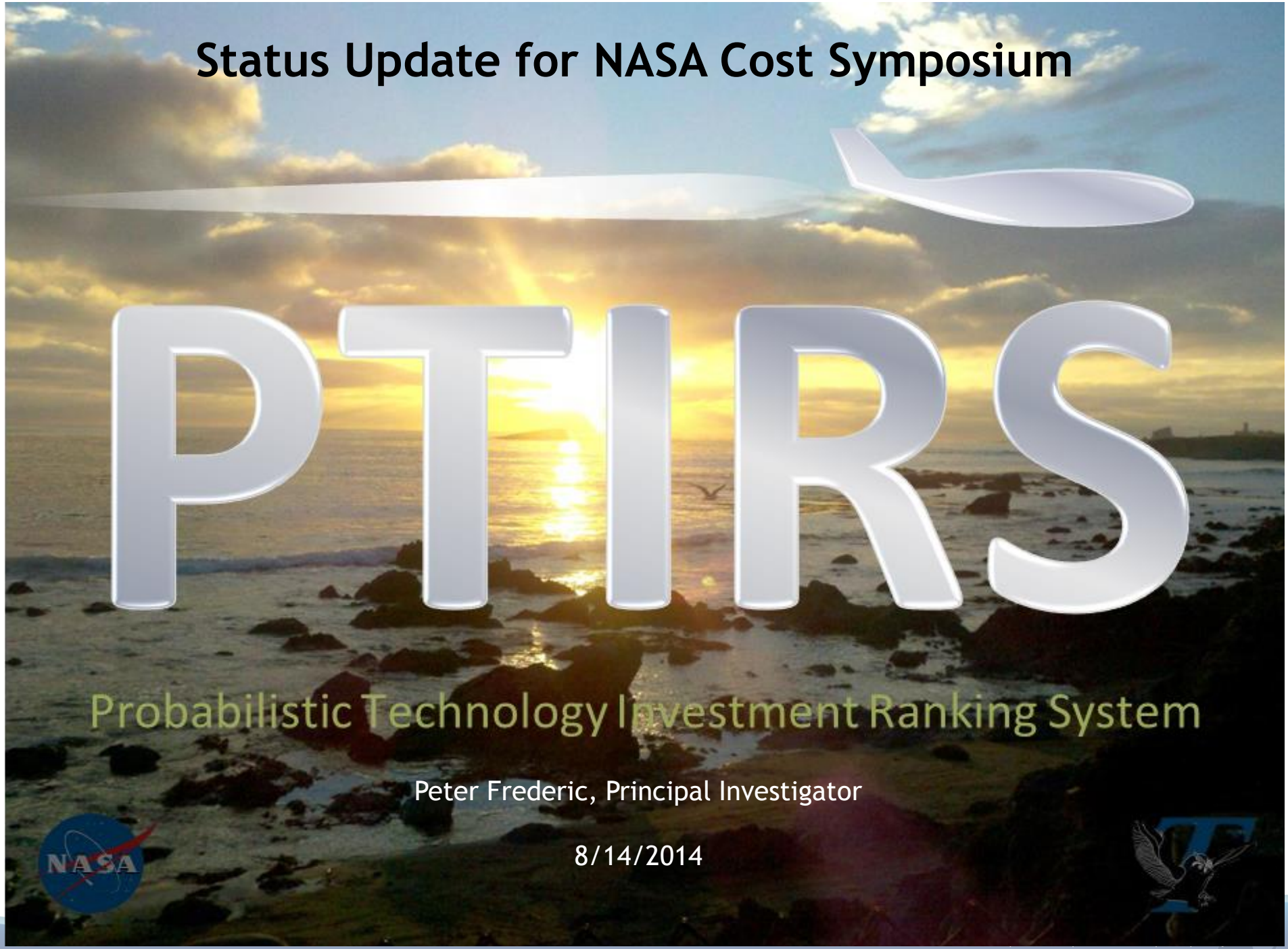
Status Update for NASA Cost Symposium



Peter Frederic, Principal Investigator

8/14/2014

PTIRS

Introduction

- **PTIRS is a tool that is used to build a business case for incorporating a technology or suite of technologies on a future aircraft**
- **Research topic**
  - "An area of interest for development under this NRA solicitation is technology maturation and certification cost estimation and integration of cost analyses into the conceptual design process to have a systematic way of prioritizing investment in particular technologies."
- **Approach**
  - Developed an Excel-based tool that combines a complete life-cycle economic analysis model, an infinitely flexible technology cost estimating tool, an integrated weight resizing tool, and pervasive Monte Carlo risk analysis capability

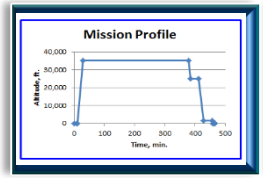
PTIRS

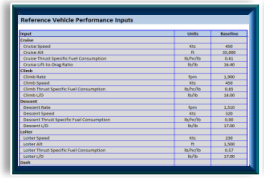
Background

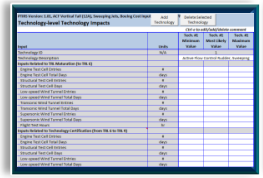
- **Sponsor: NASA Environmentally Responsible Aviation (ERA) Project, Integrated Systems Research Program, Aeronautics Research Mission Directorate**
  - ERA Project goals: simultaneous reduction of community noise, NOx emissions, and fuel consumption
- **NASA Research Announcement Topic: "Enhancement and Application of System Design and Analysis Tools"**
- **Period of Performance: May 2012 to May 2014, extended to Jan. 2015**
- **PTIRS Version 1.0 successfully delivered May 2014**
- **NASA COTR: Craig Nickol**
- **Principal Investigator: Peter Frederic**
- **Program Manager: Rey Carpio**

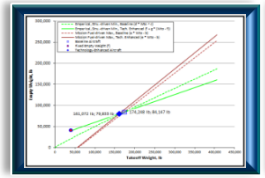
PTIRS

Architecture










2 Programmatics, Mission, and Configuration → 3 Performance and Design → 4 Technology Impacts → 5 Technology Cost Tool → 7 Weight Resizing → 8 Economic Analysis Module

- Milestones
- Heritage Factors
- Fleet Size
- Flight Rate
- Mission Profile
- Payload
- Vehicle Config.

- Payload
- SFCs
- L/Ds
- Noise Footprints
- Emissions
- R & M Factors
- Mass Properties

- Impact Factors
  - Mass Properties
  - SFCs
  - L/Ds
  - Noise Footprints
  - Emissions
  - R & M Factors
  - New Components
- *All impacts specified with uncertainty distributions*

- Multi-category Dev't, Prod., O&S CERs
- Interfaces to COTS Estimating Tools

- Override Mass Properties

External Sizing Tools

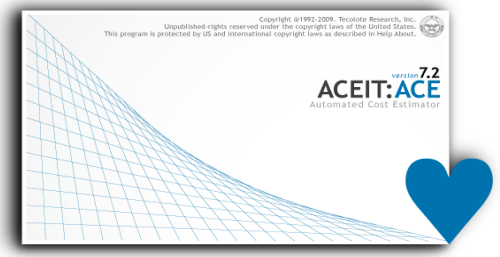
- Fundamental Transport Aircraft CERs (Tech. Matur., Dev't, Prod., O&S)
- Economic & Programmatic Wraps
- Inflation Factors
- Learning Curves
- Net Present Value Factors

1 Reference Configuration Database

6 Ad-hoc Technology Cost Tool Database

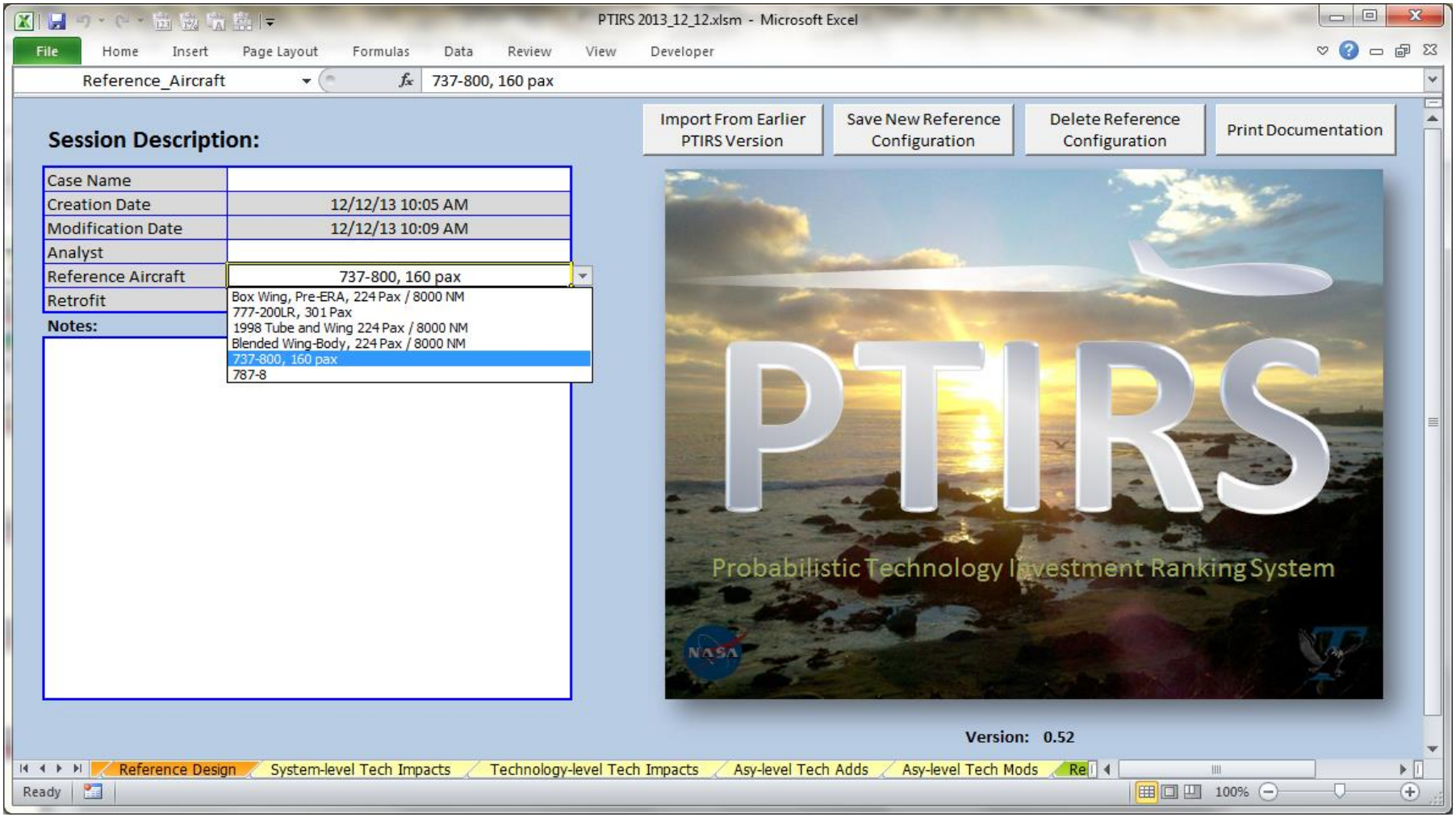
PRICE-H ™

SEER ™

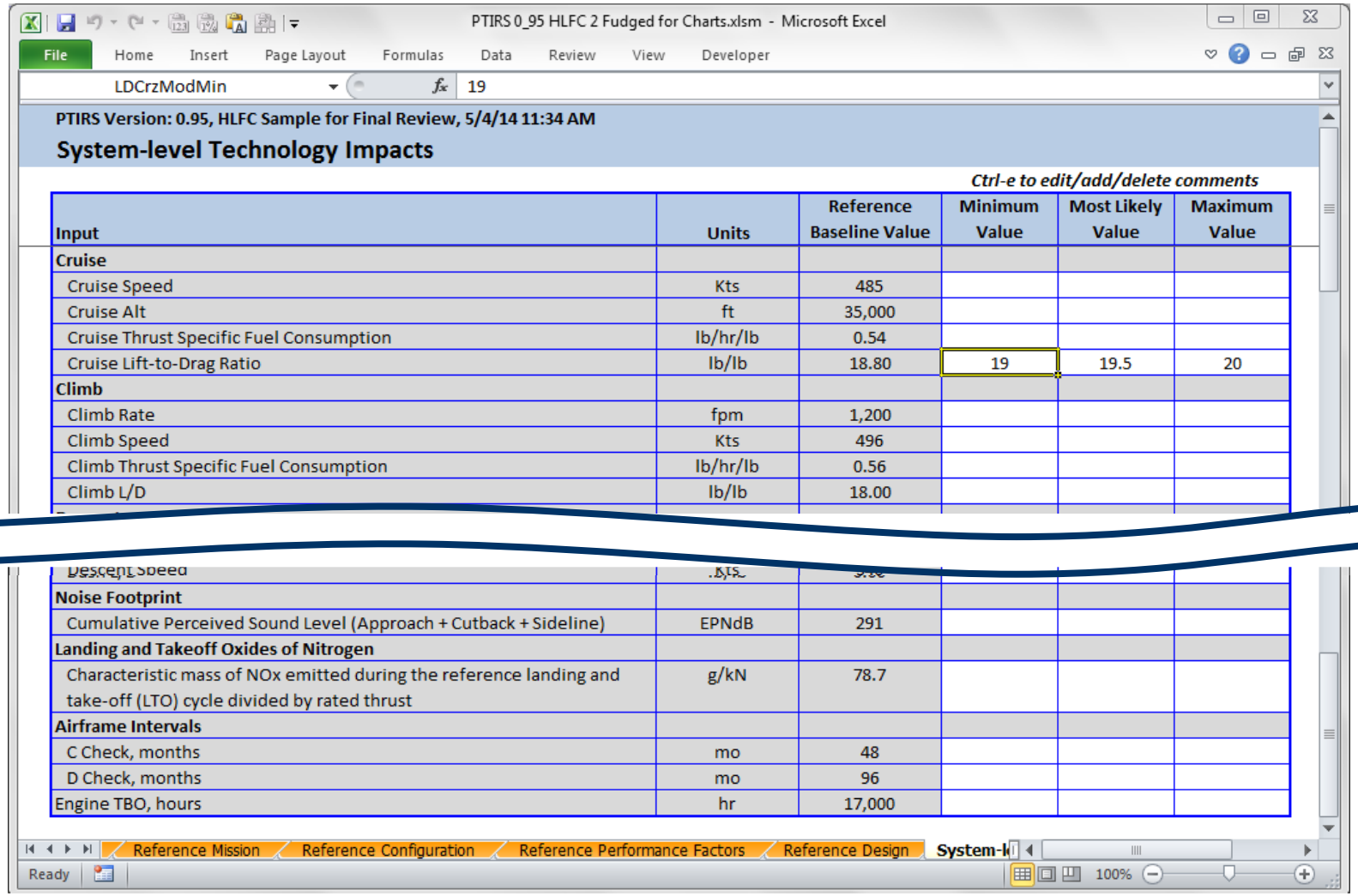


PTIRS

Selecting Reference Configuration

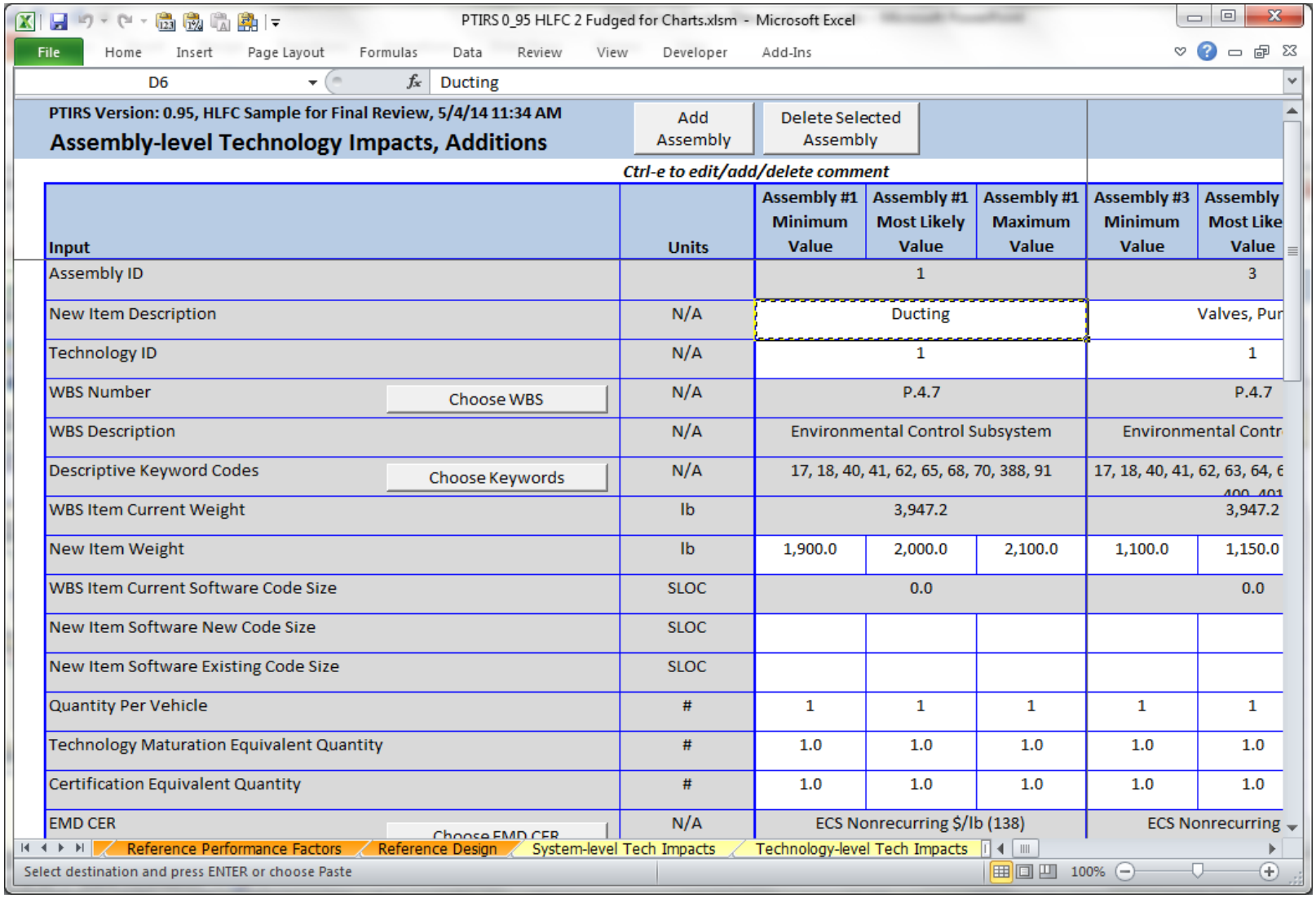


Specifying Performance Impacts



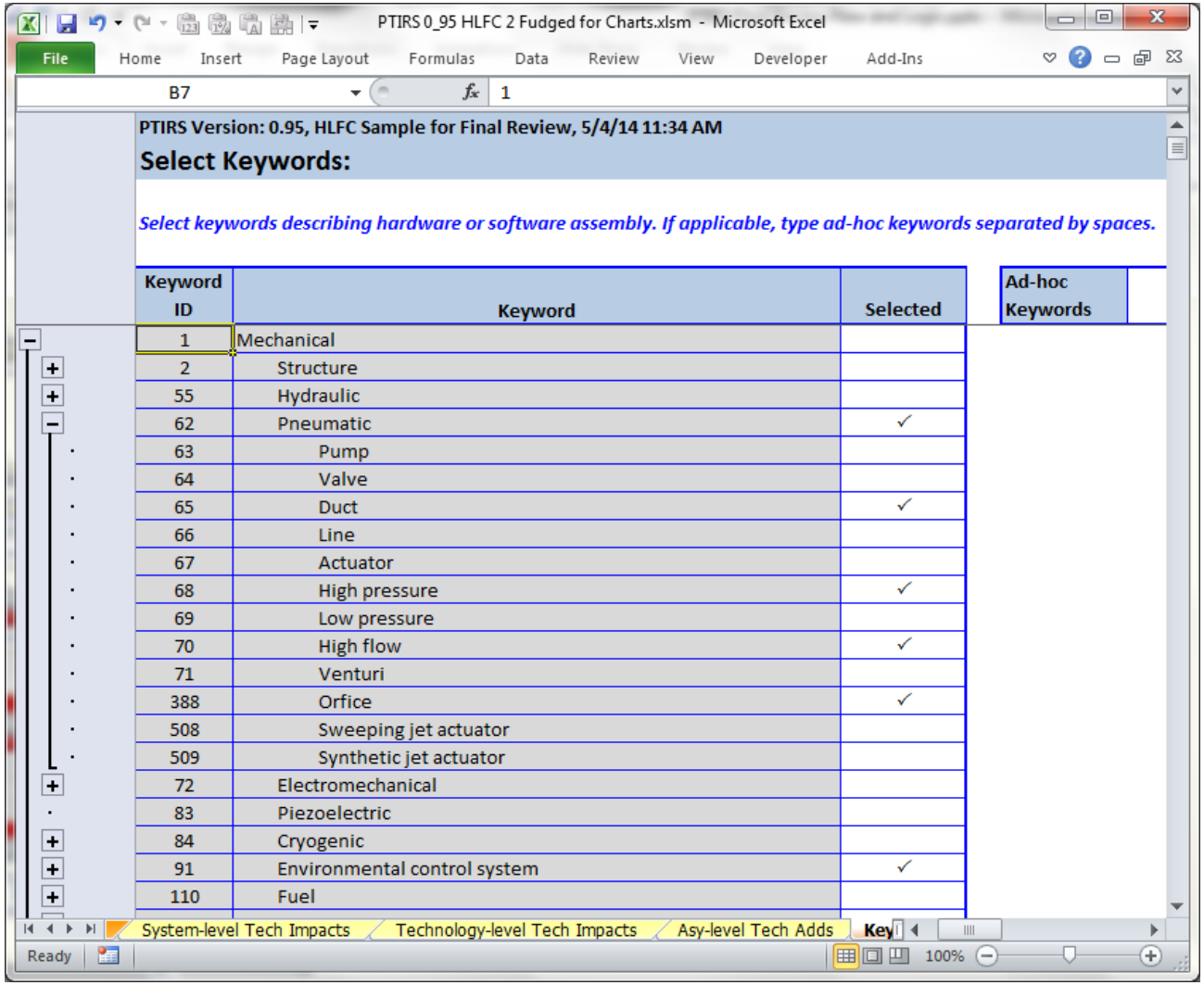
Input	Units	Reference Baseline Value	Minimum Value	Most Likely Value	Maximum Value
Cruise					
Cruise Speed	Kts	485			
Cruise Alt	ft	35,000			
Cruise Thrust Specific Fuel Consumption	lb/hr/lb	0.54			
Cruise Lift-to-Drag Ratio	lb/lb	18.80	19	19.5	20
Climb					
Climb Rate	fpm	1,200			
Climb Speed	Kts	496			
Climb Thrust Specific Fuel Consumption	lb/hr/lb	0.56			
Climb L/D	lb/lb	18.00			
Descent Speed	Kts				
Noise Footprint					
Cumulative Perceived Sound Level (Approach + Cutback + Sideline)	EPNdB	291			
Landing and Takeoff Oxides of Nitrogen					
Characteristic mass of NOx emitted during the reference landing and take-off (LTO) cycle divided by rated thrust	g/kN	78.7			
Airframe Intervals					
C Check, months	mo	48			
D Check, months	mo	96			
Engine TBO, hours	hr	17,000			

Describing Technology Implementation

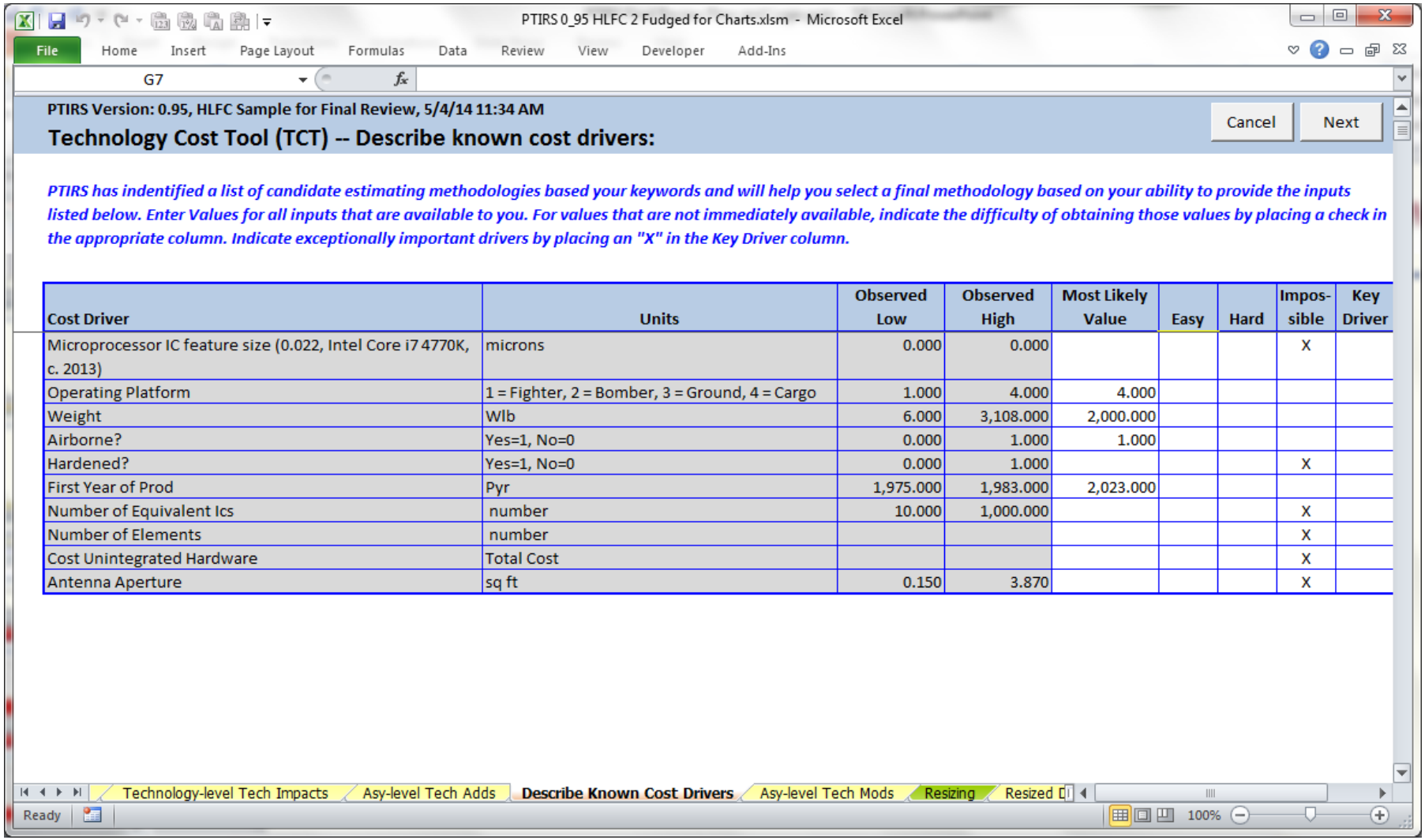


Input		Units	Assembly #1 Minimum Value	Assembly #1 Most Likely Value	Assembly #1 Maximum Value	Assembly #3 Minimum Value	Assembly Most Like Value
Assembly ID			1				3
New Item Description		N/A	Ducting				Valves, Pur
Technology ID		N/A	1				1
WBS Number	Choose WBS	N/A	P.4.7				P.4.7
WBS Description		N/A	Environmental Control Subsystem				Environmental Contr
Descriptive Keyword Codes	Choose Keywords	N/A	17, 18, 40, 41, 62, 65, 68, 70, 388, 91				17, 18, 40, 41, 62, 63, 64, 6
WBS Item Current Weight		lb	3,947.2				3,947.2
New Item Weight		lb	1,900.0	2,000.0	2,100.0	1,100.0	1,150.0
WBS Item Current Software Code Size		SLOC	0.0				0.0
New Item Software New Code Size		SLOC					
New Item Software Existing Code Size		SLOC					
Quantity Per Vehicle		#	1	1	1	1	1
Technology Maturation Equivalent Quantity		#	1.0	1.0	1.0	1.0	1.0
Certification Equivalent Quantity		#	1.0	1.0	1.0	1.0	1.0
EMD CER	Choose EMD CER	N/A	ECS Nonrecurring $/lb (138)			ECS Nonrecurring	

Use Keywords to Describe New Assembly

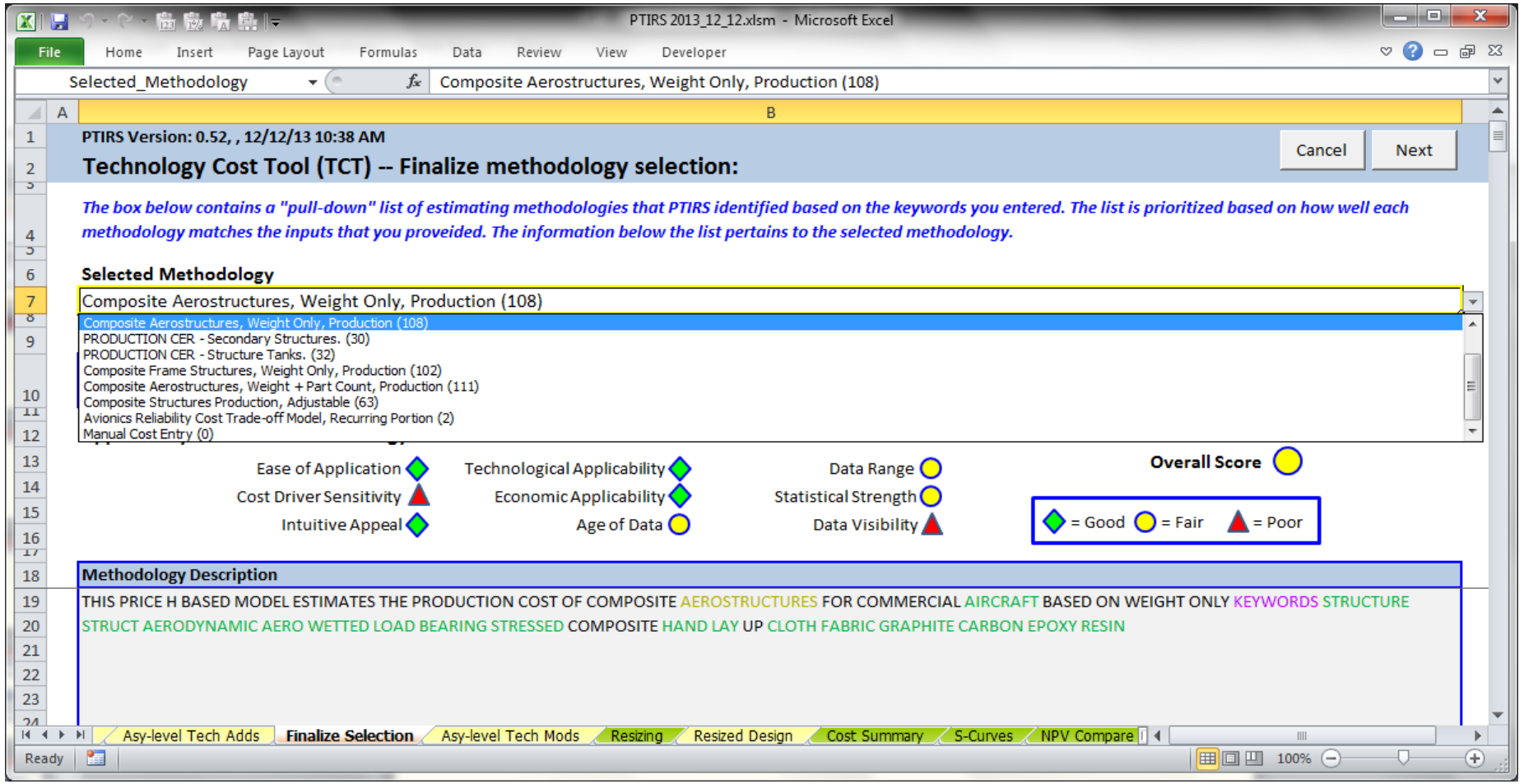


Tell PTIRS TCT What You Know



Cost Driver	Units	Observed Low	Observed High	Most Likely Value	Easy	Hard	Impos-sible	Key Driver
Microprocessor IC feature size (0.022, Intel Core i7 4770K, c. 2013)	microns	0.000	0.000				X	
Operating Platform	1 = Fighter, 2 = Bomber, 3 = Ground, 4 = Cargo	1.000	4.000	4.000				
Weight	Wlb	6.000	3,108.000	2,000.000				
Airborne?	Yes=1, No=0	0.000	1.000	1.000				
Hardened?	Yes=1, No=0	0.000	1.000				X	
First Year of Prod	Pyr	1,975.000	1,983.000	2,023.000				
Number of Equivalent Ics	number	10.000	1,000.000				X	
Number of Elements	number						X	
Cost Unintegrated Hardware	Total Cost						X	
Antenna Aperture	sq ft	0.150	3.870				X	

Selecting Cost Methodologies for Unique New Components



Viewing Resizing Results

PTIRS 0_95 HLFC 2 Fudged for Charts.xlsm - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View Developer

B3

PTIRS Version: 0.95, HLFC Sample for Final Review, 777-200LR, 301 Pax, 5/4/14 11:34 AM

Aircraft First-Order Weight Resizing Module

Segment	Driver	Driver Value	Baseline Relative Finish Weight Factor	Tech-Enhanced Relative Finish Weight Factor
Start	N/A	0	1.000	1.000
Taxi	min	9	0.998	0.998
Takeoff	N/A	0	0.996	0.996
Climb	ft	30,000	0.982	0.982
Cruise	nmi	7,253	0.651	0.665
Descend	ft	5,000	0.998	0.998
Cruise	nmi	200	0.988	0.989
Descend	ft	23,500	0.993	0.993
Loiter	min	30	0.987	0.987
Descend	ft	1,500	1.000	1.000
Land	N/A	0	0.998	0.998
Taxi	min	5	0.999	0.999
Reserve	%	5%	0.981	0.981
		0	1.000	1.000
		0	1.000	1.000
		0	1.000	1.000
		0	1.000	1.000
		0	1.000	1.000
		0	1.000	1.000
		0	1.000	1.000
		0	1.000	1.000
		0	1.000	1.000
		0	1.000	1.000

Baseline Aircraft	
Calc'd Mission Wgt. Fraction	0.600
Calibration Factor	0.991
(a) Calib. Mission Wgt. Fraction	0.594
(adjusted for trapped fuel)	
(b) Crew + Payload Weight, lb	150,414
(c) Empirical Weight Exponent	0.940
(d) Adjusted Weight Multiplier	0.895
Takeoff Weight, lb	765,254
Empty Weight, lb	303,784
Useable Fuel Weight, lb	309,805

Technology-Enhanced Aircraft	
Calc'd Mission Wgt. Fraction	0.613
(e) Calib. Mission Wgt. Fraction	0.607
(adjusted for trapped fuel)	
Adj. Empty Wgt. (no resizing), lb	306,868
(f) Fixed Empty Weight, lb	118,992
(g) Empty Weight Slope	0.291
Takeoff Weight, lb	**742,752**
Empty Weight, lb	**300,327**
Useable Fuel Weight, lb	**290,761**

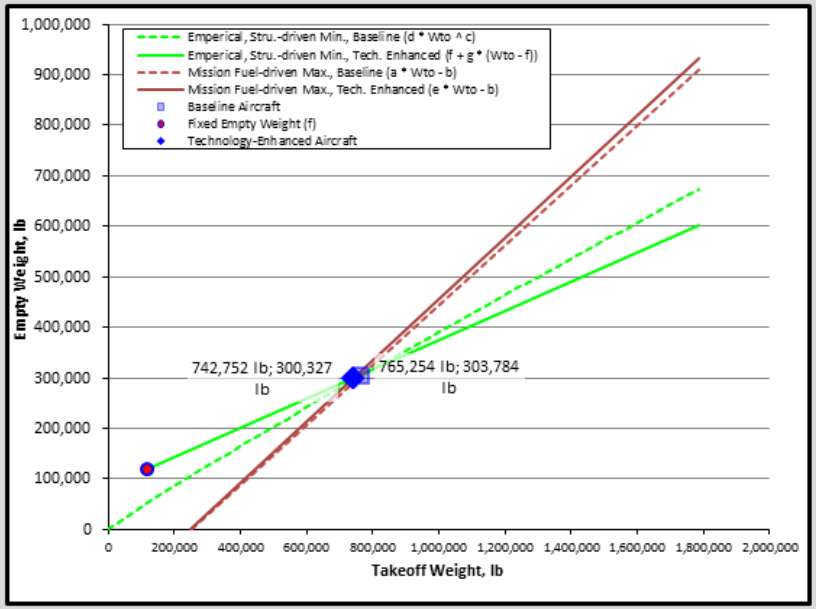


Chart Area

Technology-level Tech Impacts | Asy-level Tech Adds | Asy-level Tech Mods | **Resizing** | Resized Design | Cost Summary | S-Curves | NPV Co

Ready 90%

Viewing Business Case Results

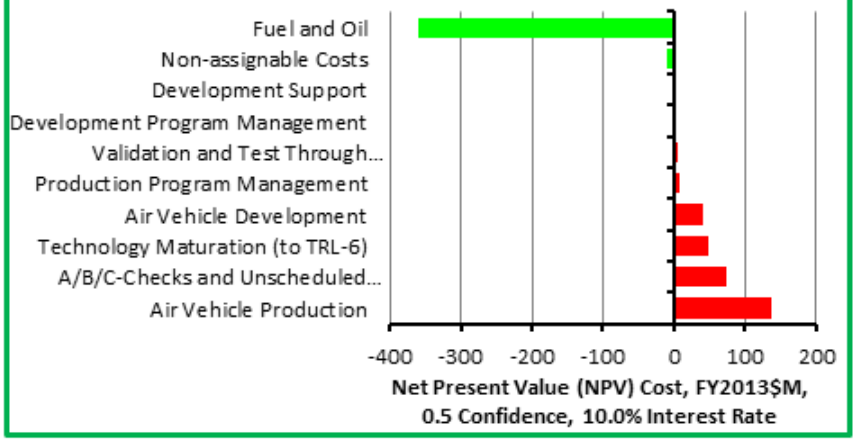
HLFC Sample for Final Review

Date: 7/29/14 1:31 PM Weight Resizing: Yes
Reference Aircraft: 737-800, 160 pax

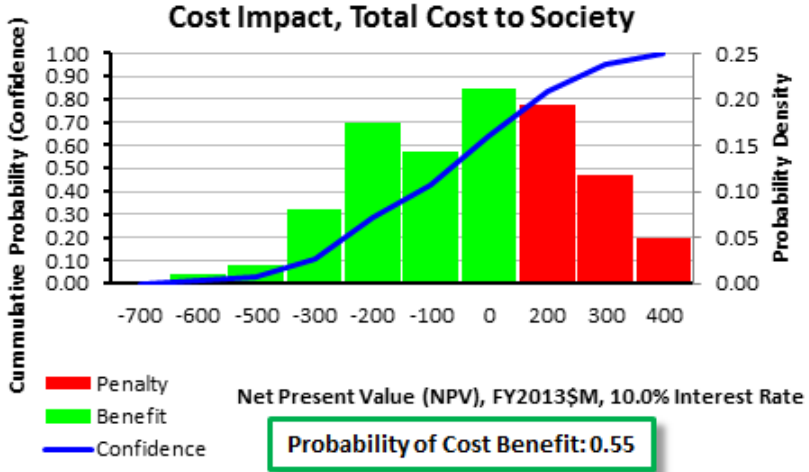
Total Cost to Society

Net Present Value (NPV) Cost, FY2013$M, 0.5 Confidence, 10.0% Interest Rate	Baseline Aircraft	Enhanced Aircraft	Cost Impact (- is good)
	48,814	**48,819**	**-53**

Top 10 Cost Impacts



Cost Impact, Total Cost to Society



Probability of Cost Benefit: 0.55

Comparative Values (0.5 Confidence)	Reference Aircraft	Enhanced Aircraft	Impact (- is good)
Takeoff Weight (Lb)	174,248	174,491	243
Empty Weight (lb)	84,147	86,282	2,135
Useable Fuel Weight (lb)	46,766	44,858	-1,908
Cummulative Perceived Sound Level (EPNdB)	276.0	276.0	0.0
Landing and Takeoff NOx (g/kN)	34.8	34.8	0.0
First Unit Production Cost (FY2013$M, 0.5)	162.5	165.4	2.7
Average Unit Production Cost (FY2013$M, 0.5)	25.8	26.3	0.4
Tot. A/C-related Ops Cost per Hr (FY2013$, 0.5)	5,160.6	5,091.2	-81.0
Total Cost per Hr (FY2013$, 0.5)	12,941.2	12,886.0	-66.8
Cost per Avail. Statute Seat-Mile (FY2013$, 0.5)	0.1764	0.1757	-0.0008

Technologies Included

- Hybrid Laminar Flow Conrol

Study Parameters	Assumed	Break-even (0.5)
Fleet Size	855	645
Design Life	20	14
NPV Interest Rate	10.0%	11.4%
Fuel Price (FY2013$/gal)	3.20	2.97

PTIRS
Version: 1.01

PTIRS

Comparison of Predicted Costs with Published Prices

	737-800	777-200LR
PTIRS Estimates, FY2013$M		
Development	6,348	17,361
Production	49,911	161,670
Flight Test Aircraft	10	9
Operational Fleet	855	855
Backup Aircraft	144	140
Development Years	8.6	8.6
Production Years	14.9	14.9
Production Start to Sale Lag, Years	1.3	1.3
Present Value Interest Rate	10%	10%
Sales Markup	25%	25%
Value of Development at End of Development	11,062	30,252
Total Payments on Development to End of Production	21,760	59,506
Production at Sale	56,671	183,565
Acquisition Total Cost with Finance Cost	78,431	243,071
Acquisition Unit Cost with Finance Cost	77.8	242.3
Unit Cost Plus Markup	**97.3**	**302.9**
Boeing.com Price	**93.8**	**306.5**
PTIRS Estimate Divided by Boeing.com	**104%**	**99%**

Comparison of Predicted Operating Costs with Actual Operating Costs

777-200LR	PTIRS 2013$M	2013$/hr	PTIRS Divided by Actual	Actual 2013$/hr
Assignable Life Cycle (Development, Production, Operations)	1,385,222	22,403		
Development	17,361	281		
Production	161,670	2,615		
Operations and Maintenance	**1,206,191**	**19,508**	**100%**	**19,538**
Flight Operations	722,818	11,690	107%	10,968
Flight Crew	92,319	1,493	103%	1,450
Fuel and Oil	453,145	7,329	105%	6,980
Insurance	1,369	22	106%	21
A/B/C/D-Checks and Unscheduled Maintenance	117,484	1,900	127%	1,500
Vehicle Level	14,083			
Airframe	19,803	909	129%	703
Propulsion	61,302	991	124%	798
Subsystems	13,227			
Avionics Hardware	1,216			
Software	7,853			
Depreciation	58,501	946	93%	1,017
Passenger Services	42,974	695	60%	1,149
Flight-line Servicing	3,162	51	72%	72
Control	3,035	49	72%	68
Landing Fees	3,748	61	61%	99
Other Indirect Costs	430,454	6,962	97%	7,182
			American Air Lines Inc.	

ERA Technologies Addressed

- Adaptive Compliant Trailing Edge (ACTE) – preliminary results
- Flap-edge and Landing Gear Noise Reduction – preliminary results
- Pull-truded Rod Stitched Efficient Unitized Structure – preliminary results
- High OPR Axially Staged Combustor – inputs collected from technical experts, results pending
- Highly Loaded Front Block Compressor – inputs collected from technical experts, results pending
- Large-scale GTF Soft Vanes and Over-The-Rotor Metal Foam Liners- inputs collected from technical experts, results pending
- Active Flow Control Vertical Tail – initial results briefed to ERA management

Ongoing Improvements

- **Flight demonstration aircraft estimating capability**
- **Retrofit estimating capability**
- **Improvement of noise monetization methodology**
- **Public-friendly cost-effectiveness metrics**
  - Aircraft sales price
  - Airline ticket price
  - Seat-miles per gallon

Extensibility

- PTIRS software and databases are modular allowing for extension to target platforms other than commercial transport aircraft
- For other aircraft platforms only minor WBS and Economic Analysis Module (EAM) modifications required

- For non-aero platforms, WBS, EAM, and Resizing Module modifications required, but little or no software modifications

PTIRS

Conclusions

- **PTIRS is a comprehensive tool for evaluating business cases for advanced commercial aircraft technologies from three perspectives:**
  - Manufacturer
  - Operator
  - World community
- **PTIRS Version 1.0 is a reliable tool, unique in its ability to provide logically rigorous data on which to make sound decisions in a rapidly advancing world.**
- **The PTIRS architecture is extensible to address other platforms in addition to commercial transport aircraft**